



Changes in age and size at maturity related to fishery selection: lessons learned from Alaskan populations applied to Columbia River Chinook salmon



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Acknowledge Tom Quinn and Jeff Hard

Talk outline



- Why we need to consider size-selective fishing and its consequences in fish management
- Why it is often difficult to quantify fishery selection
- Introduction of metric to quantify fishery selection
- Recreational vs. commercial fishery selection
- My work on commercial and recreational fishery selection on Alaskan salmon
- Putting things together for Columbia River Chinook salmon

Need to consider effects of fishery selection

- Humans harvest wild populations size-selectively
(Carlson et al. 2007 Ecology Letters, Kendall et al. 2009 Evolutionary Applications)



Often the harvest of wild animals by human is thought to be size-specific. Selectivity is often influenced by harvest regulations.

Need to consider effects of fishery selection

- Humans harvest wild populations size-selectively (Carlson et al. 2007 Ecology Letters, Kendall et al. 2009 Evolutionary Applications)



- Life history traits change over time (Darimont et al. 2009 PNAS)



Life history traits of harvested individuals have often changed a great deal over time, faster than traits of wild populations not exploited by humans.

The effects of size-selective harvest can often be negative, such as maladaptive traits and less sustainable populations.

Thus, resource managers want to understand these changes and how to minimize them.

Changes in the Average Size and Average Age of Pacific Salmon¹

W. E. RICKER

Department of Fisheries and Oceans, Resource Services Branch, Pacific Biological Station, Nanaimo, B.C. V9R 5K6

RICKER, W. E. 1981. Changes in the average size and average age of Pacific salmon. *Can. J. Fish. Aquat. Sci.* 38: 1636–1656.

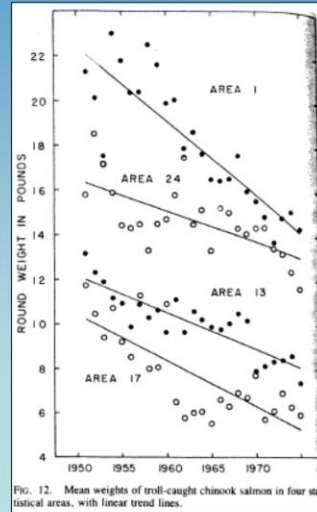
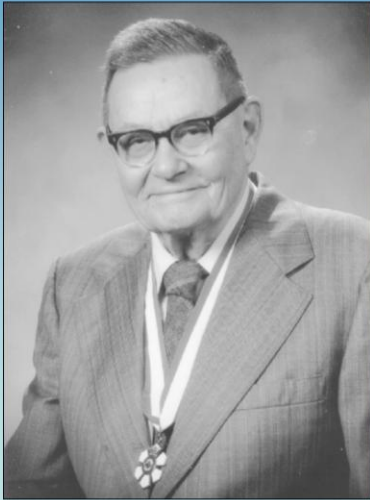


FIG. 12. Mean weights of troll-caught chinook salmon in four statistical areas, with linear trend lines.

A famous paper came out in the early 1980s by the Godfather of salmon ecology, Bill Ricker, showing that many populations of western North America Pacific salmon were getting smaller and younger. He argued that these changes were correlated with fishery selection. This was one of the papers that got us started thinking about fishery selection effects on Pacific salmon.

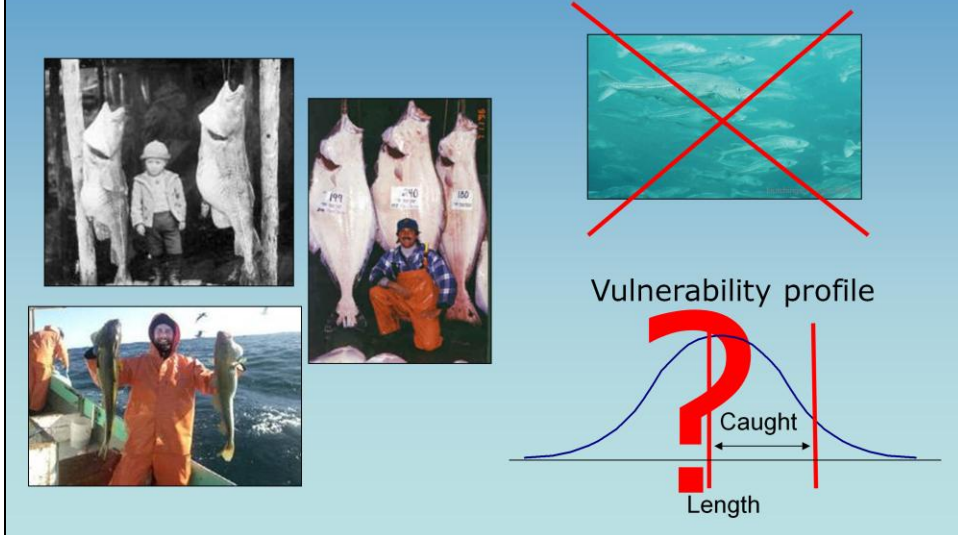
Ricker's hypotheses: why age and size at maturation are changing in Chinook salmon

- Changes in abundance of stocks with different sizes of fish
- Changes in ocean environmental conditions
- Changes in hatchery practices
- Changes in genetic makeup of a stock as different size and ages of fish are caught



Here are Ricker's hypotheses about why size and age may be changing. In many populations Ricker found in his 1981 paper that the changes were correlated more with size-selective fishing than other causes.

Difficult to quantify fishery selection



Difficult to quantify as for many fish stocks, we know sizes of fish caught by not what is not caught.

Vulnerability profile is: vulnerability of fish to being caught varies by its length, so we must know lengths of fish caught and not caught.

Vulnerability profiles not always clear.

Data requirements! For stocks where we have both catch and esc data, we can estimate these vulnerability profiles directly.

Otherwise we have to look at which kinds of gear were used to catch the fish and estimate selectivity from that.

Metric to quantify size-selective harvest

$$\text{Selection differential} = \overline{\text{length}}_{\text{escapement}} - \overline{\text{length}}_{\text{total run}}$$



Smaller fish are
escaping the fishery
than are getting caught

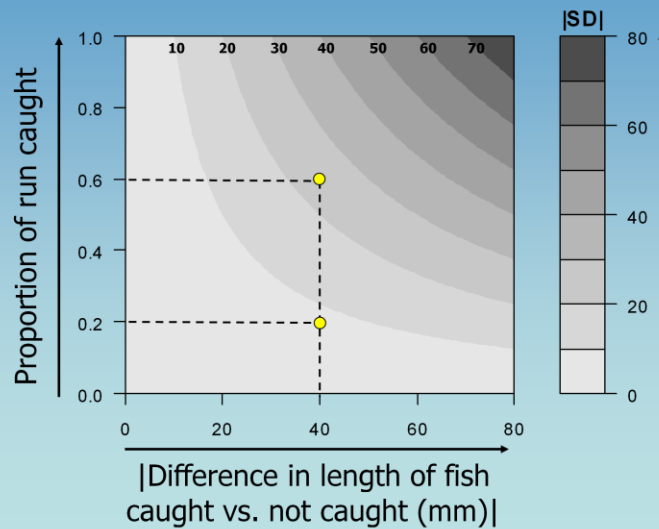


Larger fish are escaping
the fishery than are
getting caught

- Selection Differential +

Compare average value of traits before and after a selective event—in this case the fishery.

What components shape selection differentials?



You can get different selection differential values by changing just one of the values of each factor. In this case, the SD is reduced just by lowering fishing pressure.

Commercial vs. recreational fisheries



Coleman et al. 2004. The impact of United States recreational fisheries on marine fish populations. *Science*.

Cooke and Cowx. 2006. Contrasting recreational and commercial fishing: searching for common issues to promote unified conservation of fisheries resources and aquatic environments. *Biological Conservation*.

Talk about stereotypes of commercial and recreational fishing selection: recreational fishing thought to be more benign than commercial fishing, recreational fisheries generally catch fewer fish, are less damaging to the environment, overfish fewer populations, and are less selective than commercial fisheries.

However, very hard to get data on commercial fishing as it's scattered, less data are collected, often times there is hatchery supplementation.

Thus, there are very few comparisons of recreational and commercial fishery exploitation and selection.

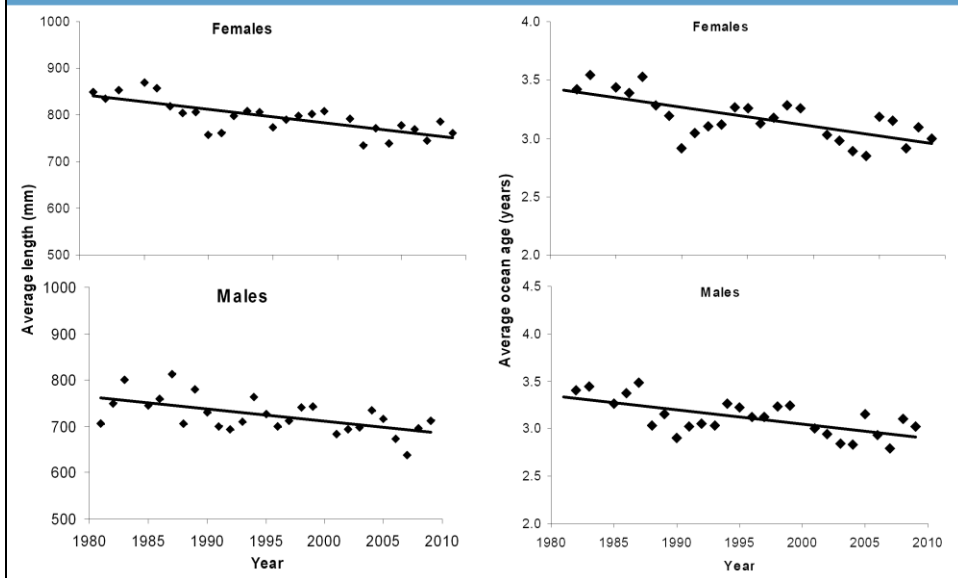
Nushagak river Chinook salmon study objectives

- Quantify trends in age and size of Nushagak River Chinook salmon 1981-2009
- Quantify commercial and recreational fishery selection



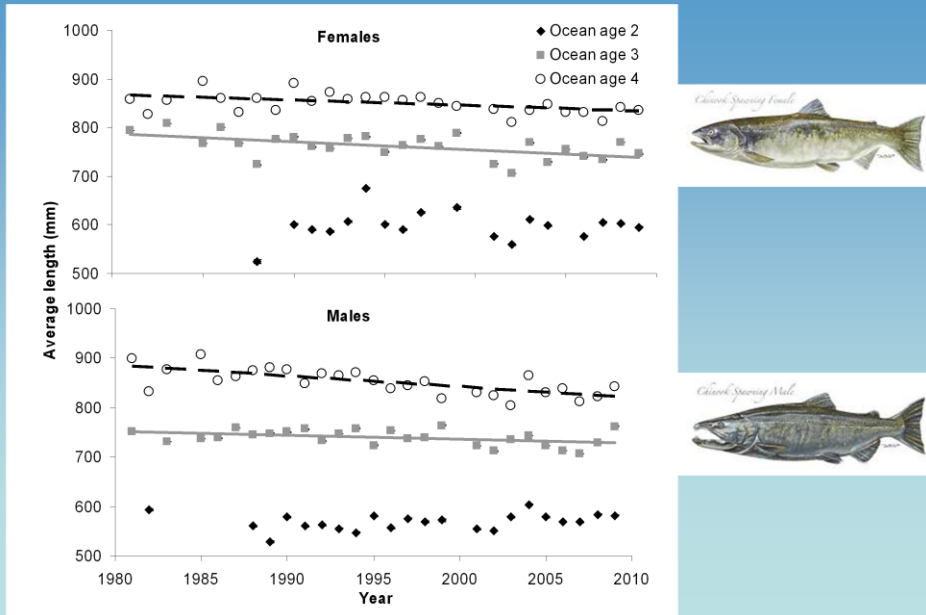
This is a great model system. It's located in SW Alaska and we have great catch and escapement data from 30 years. Also no hatcheries!

Males and females have gotten shorter over time...and younger



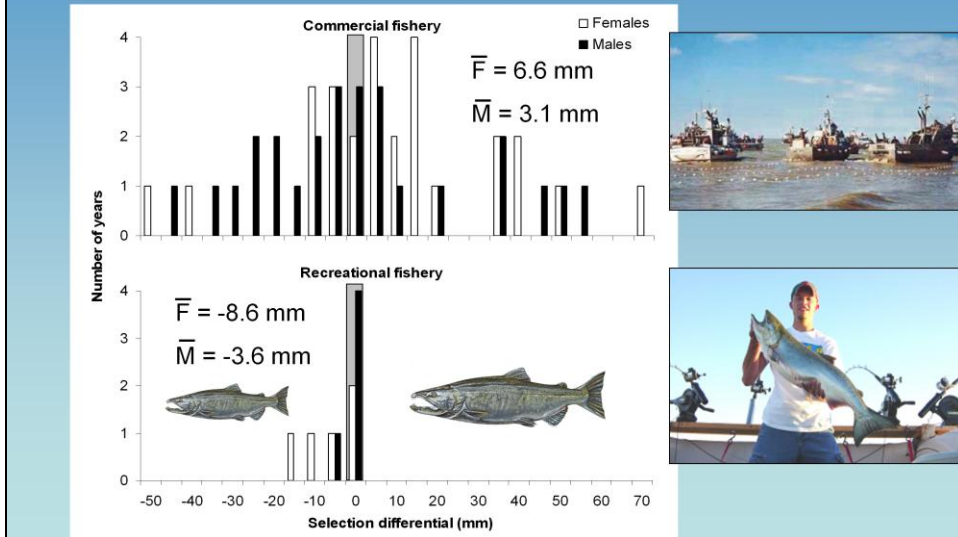
Both male and female Chinook salmon have gotten significantly smaller and younger over time

Fish are shorter at age over time



And smaller at the dominant ocean ages.

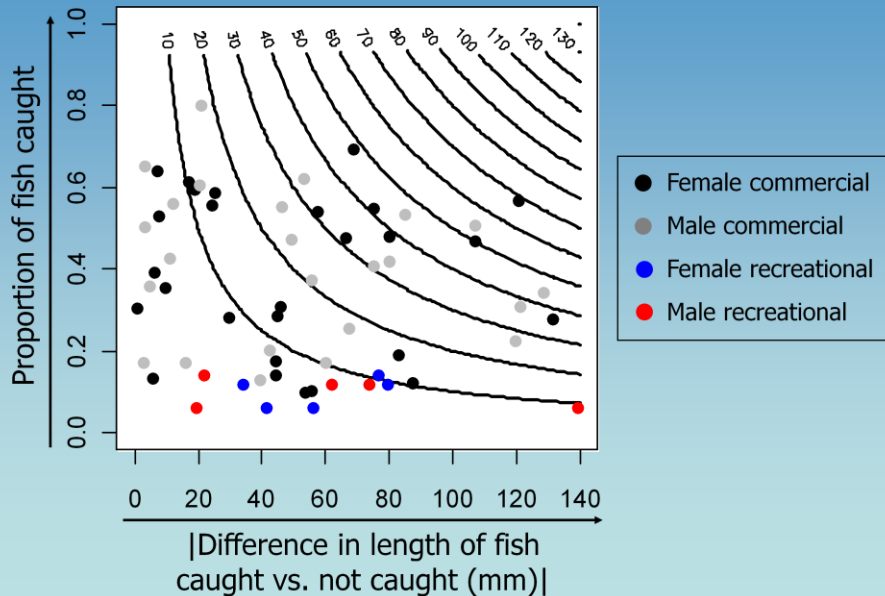
Commercial fishery selection: variable and of larger magnitude, recreational fishery selection: directional and of smaller magnitude



These figures show selection differentials, which are different in length of fish before vs. after a selective event—in this case the fishery. Negative values mean larger fish caught, smaller fish not caught and positive values mean smaller fish caught, larger fish not caught.

Gear matters—the commercial fishery in general uses smaller mesh gear as it mostly targets sockeye salmon.

Nushagak Chinook SDs



This shows that the recreational fishery harvests a smaller proportion of the fish available to it, which means its SDs are smaller than those of the commercial fishery, even if it is often as size-selective as the commercial fishery.

Is fishery selection correlated with length changes?

	Commercial		Recreational		Average	
	Female	Male	Female	Male	Female	Male
average annual SD 1981-2009 (mm)	6.6	3.1	-8.6	-3.6	-2.0	-0.5



	Female	Male
average annual length change 1981-2009 (mm)	-3.1	-2.6

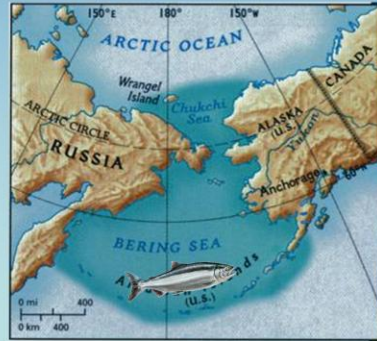
Size-selective fishing can contribute to observed changes in length and length at age.

However, size-selective fishing is likely not the sole factor.

SDs are additive, so we added the commercial and recreational SDs to get the annual average value. We can compare that with the annual average change in length. We see that they are both negative, but the annual length change is greater than the SD in magnitude.

What's going on?

- Changes in age and size are likely also related to environmental conditions
- We should still be careful about recreational fishery selectivity



Environmental conditions include temperature both in freshwater and the ocean, changes in prey and predator distributions, etc. that affect fish growth.

Competition with hatchery salmon or other fish in general could also affect fish growth.

We may need to reduce the number of fish that recreational fishermen are allowed to keep or the maximum size of fish that fishermen are allowed to keep

Overall, we need to consider both direct human-caused influences (such as fishing) and environmental changes when understanding patterns of trait changes in fish populations

Further analyses

- Can size-selective fishing influence age and size at maturation patterns?

What about other factors?

- Quantitative genetic models
- Probabilistic maturation reaction norms



Swain et al. 2007. Evolutionary response to size-selective mortality in an exploited fish population. *Proceedings of the Royal Society B*.

Dieckmann and Heino. 2007. Probabilistic maturation reaction norms: their history, strengths, and limitations. *Marine Ecology Progress Series*.

These novel methods help shed light on whether genetic evolutionary changes associated with size-selective fishing contribute to length and age at maturation patterns seen in exploited fish populations. They are helpful as they are more mechanistic tools and show the influence of various factors including fishing, environmental changes affecting growth, and other factors.

Quantitative genetic models

PROCEEDINGS
OF
THE ROYAL
SOCIETY **B**

Proc. R. Soc. B (2007) 274, 1015–1022
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Published online 30 January 2007

Evolutionary response to size-selective mortality in an exploited fish population

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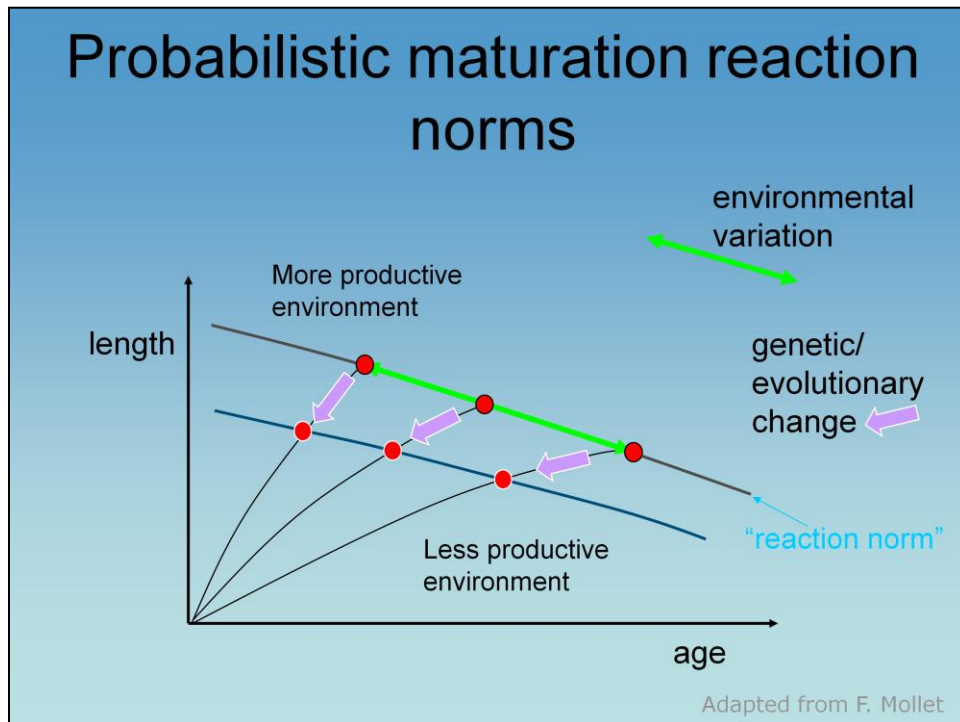
²Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, British Columbia V9R 5K6, Canada

Many collapsed fish populations have failed to recover after a decade or more with little fishing. This may reflect evolutionary change in response to the highly selective mortality imposed by fisheries. Recent experimental work has demonstrated a rapid genetic change in growth rate in response to size-selective harvesting of laboratory fish populations. Here, we use a 30-year time-series of back-calculated lengths-at-age to test for a genetic response to size-selective mortality in the wild in a heavily exploited population of Atlantic cod (*Gadus morhua*). Controlling for the effects of density- and temperature-dependent growth, the change in mean length of 4-year-old cod between offspring and their parental cohorts was positively correlated with the estimated selection differential experienced by the parental cohorts between this age and spawning. This result supports the hypothesis that there have been genetic changes in growth in this population in response to size-selective fishing. Such changes may account for the continued

$$\Delta Length = \Delta Genetic + \Delta Env,$$

where $\Delta Genetic = h^2 * SD$

We can create regression models that explain the change in fish length incorporating both environmental factors and a genetic term. If including the genetic term makes the models better able to explain the change in length, then this supports the finding that fishing can have a genetic change on size at maturation in the harvested fish population.



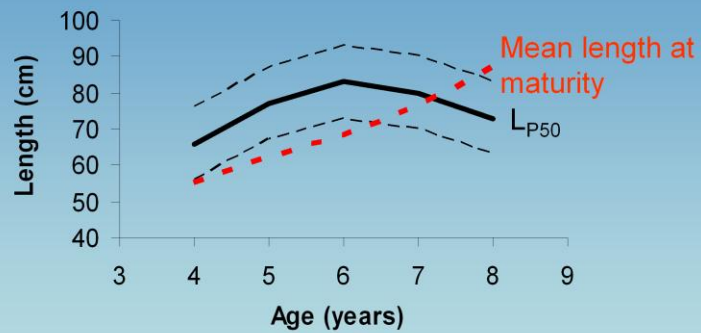
Norms of reaction show ranges of potential phenotypes, such as different ages and sizes at maturity, that a given genotype could develop if an individual is exposed to different environmental conditions.

PMRNs describe when individuals undergo maturation. Defined by **probability of maturation** in next season as a function of an individual's size and age. They may help understand if maturation changes due to environmental or genetic effects (=evolution). Age and size at maturation differences due to growth and mortality variation are **environment** responses if they **follow same** reaction norm.

Change in shape or position of PMRN → life history polymorphisms, maturation trend, or fisheries induced evolution.

This is the **probability** of maturation (so it's relative, it's a threshold). This only shows the midpoints.

PMRNs



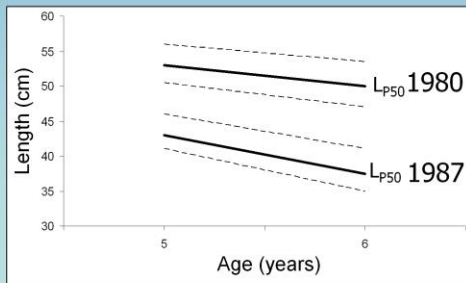
Heino et al. 2002. Evolution. Measuring probabilistic reaction norms for age and size at maturation.

Note that the PMRN midpoint (here the LP50) is different than the mean length at maturation. It's the probability that 50% of fish will have matured when they reach that length for a given age.

PMRN example



- Northern cod: in some heavily exploited stocks, PMRNs shifted to smaller sizes and younger ages over time, consistent with fishing pressure



Olsen et al. 2004. Nature. Maturation trends indicative of rapid evolution preceded the collapse of northern cod.

Columbia River Chinook salmon

- How can we apply what we've learned from Alaskan salmon to Columbia River fish?
 - For some stocks we may be able to estimate fishery selection directly
 - We can also estimate selectivity from gear used to harvest the fish
 - Do know exploitation rates by stock
 - With this information selection differentials can be estimated by stock

Quantifying fishing gear size-selectivity given gear types used :

- Kuparinen et al. 2009. Estimating fisheries-induced selection: traditional gear selectivity research meets fisheries-induced evolution. *Evolutionary Applications*.
- Jørgensen et al. 2009. Size-selective fishing gear and life history evolution in the Northeast Arctic cod. *Evolutionary Applications*.
- Hamley. 1975. Review of gillnet selectivity. *Journal of the Fisheries Research Board of Canada*.
- Millar and Fryer. 1999. Estimating the size-selection curves of towed gears, traps, nets, and hooks. *Reviews in Fish Biology and Fisheries*.
- Fujimori and Tokai. 2001. Estimation of gillnet selectivity curve by maximum likelihood method. *Fisheries Science*.

Columbia River Chinook salmon stocks

- Spring Chinook: fishery entirely in-river; includes sport, non-tribal commercial, and tribal fisheries

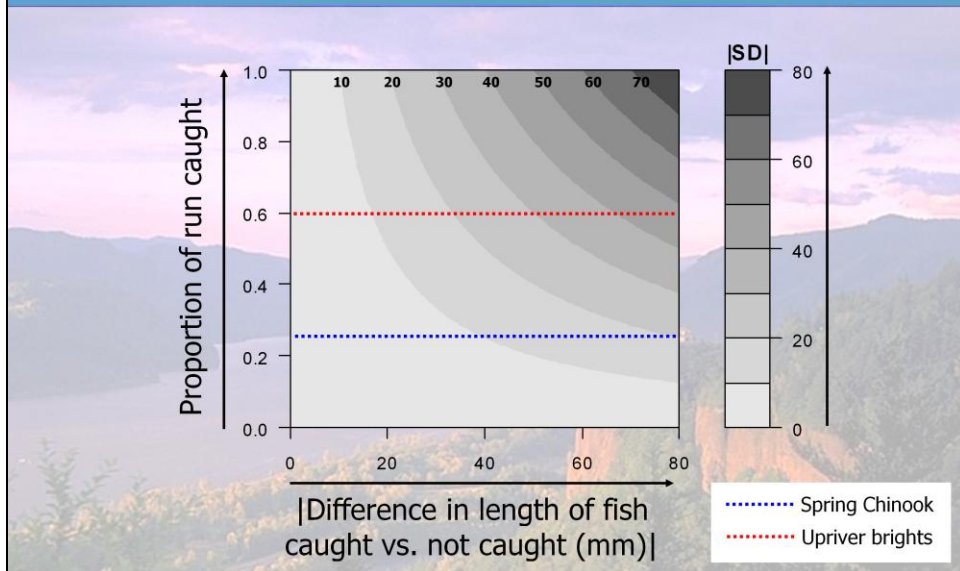
Year	Ocean exploitation rate	In-river exploitation rate	Total exploitation rate	Total escapement
2009	-	25.6%	25.6%	74.4%

- Summer and Fall Chinook: in-river and ocean fisheries

Year	Ocean exploitation rate	In-river exploitation rate	Total exploitation rate	Total escapement
2007	32.5%	26.9%	59.5%	40.5%

The bottom example is for upriver brights, which are fall Chinook.

Potential Columbia River Chinook selection differentials—2007



The SDs for the upriver brights are conservative as ocean fishing on immature fish may have even a stronger effect on age and size at maturation than in-river (terminal) fishing on maturing individuals.

Once we have information on selection differentials, we can use selection differentials to:

- 1) Create quantitative genetics models to understand impacts of fishery selection and environmental factors on life history traits
- 2) Calculate maturation reaction norms to understand potential genetic changes associated with fishery selection

Ricker's hypotheses: why age and size at maturation are changing in Chinook salmon

- Changes in ocean environmental conditions
- Changes in hatchery practices
- Changes in abundance of stocks with different sizes of fish
- Changes in genetic makeup of a stock as different size and ages of fish are caught



Just to bring us back to this point, and remember that fishing should be considered for its impacts on age and size at maturation.

Age and size changes in Columbia River Chinook: challenges but opportunities

- Nushagak River: simple system, no hatcheries, lots of data
 - Can estimate selection differentials and contribution of size-selective fishing to age and size at maturation changes relatively easily
- Columbia River: more complex!
 - But we do have data to estimate selection differentials and see if fishing is contributing to trait changes



We currently have the tools to better understand the whether selective fishing is resulting in genetic changes in exploited fish populations and its role in population sustainability. We have data from relatively simple populations in Alaska to carry out these analysis. The Columbia River stocks are more complex, but we can still carry out some analyses and it is important to do so. Fishing is one of the few factors affecting age and size at maturation that we have management control over so it's especially important to examine this potential influence on age and size at maturation.

What are the implications of selective fishing and resulting age and size at maturation on sustainable fish populations and fishing? Fish becoming smaller and younger may be a natural adaptation to them being harvested. But it doesn't guarantee persistence of populations with continued harvest. We've seen lots of studies related changes in age and size at maturation correlated with lower yield and even populations crashes. So I argue that managers do need to worry about fish becoming smaller and younger over time, and if we find out that fishing may be related to these trends we need to change our management of exploited populations.

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